The Effect of Semantic Radical Deformation on Abstract Semantic Radical Identity Representations: A Comparative Study of L1 speakers and L2 Learners

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Abstract

Semantic radicals provide information on semantic categories and play a crucial role in the decoding and reading of Chinese characters for both native and non-native speakers. However, existing research has not sufficiently examined the representation of abstract semantic radical identity and has overlooked the degree of deformation as a factor. This study uses a masked-priming semantic judgement task (Experiment 1) and a same-different judgement task (Experiment 2) to investigate how the deformation degree of semantic radicals affects the Chinese learners' abstract representations of these radicals. Results from Experiment 1 indicate that for native speakers, the reaction time under identity prime is faster than that under control prime regardless of the degree of deformation. In contrast, second language learners only exhibit this advantage when the deformation degree is low, with no significant difference when the deformation degree is high, suggesting that deformation degree affects abstract semantic radical identity representations of L2 learners. Experiment 2 found inhibition effects under identity conditions for both native speakers and L2 learners, showing that both groups have mastered semantic radicals with a high

deformation degree. These results indicate that the experimental task influences the results and that L2 learners are more affected by the task. Understanding the impact of semantic radical deformation on learners' abstract representational abilities helps teachers to adjust their pedagogical strategies in order to provide more precise guidance and recommendations for Chinese character instruction.

Keywords: abstract semantic radical identity representations; deformation degree; Chinese second language learners; masked-priming semantic judgement task; same-different judgement task

Introduction

Abstract representation refers to representing or presenting things or concepts in a generalized or symbolic way. This type of representation typically does not rely on the specific details of the things or concepts but instead extracts common features to capture essential attributes, allowing knowledge to be generalized across different contexts (Johnston & Fusi, 2023). Abstract representation helps people grasp the essence of things more clearly, thereby enhancing their understanding and application of knowledge. In research on alphabetic languages, evidence of abstract letter identity representations has been found, where the lowercase "a" and uppercase "A" are recognized as the same identity during letter recognition, unaffected by visual form (Bowers et al., 1998; Kinoshita & Kaplan, 2008; Schubert et al., 2018). Similarly, certain semantic radicals in Chinese characters have developed different forms, such as"水" and "氵" .This characteristic of semantic radicals raises the question of whether abstract semantic radical identity representations exist in Chinese characters, where readers ignore the visual form differences of semantic radicals and recognize their common semantic or conceptual attributes, grouping differently shaped radicals into a single category. In Chinese, phonograms (that combine semantic and phonetic radicals to convey both meaning and sound) make up as much as 80% of all characters, and semantic radicals provide semantic clues for characters (Zhou et al., 2013). The ability of learners to represent semantic radicals with different forms could facilitate Chinese character recognition. Li et al. (2021) found that native Chinese speakers have formed abstract semantic radical identity representations, but this study overlooked the impact of the deformation degree of semantic radicals on forming abstract representations. During the evolution of Chinese characters, the degree of deformation of semantic radicals varies (Sun, 2018). For example, the deformation degree of “水”－“氵” 木fers from “木”－“ ”,

with the former having lower orthographic similarity. It is unclear whether the deformation degree affects orthographic similarity and, in turn, influences learners' abstract identity representation of semantic radicals. Additionally, research has found that orthographic knowledge plays a more critical role in Chinese learning than in alphabetic language learning (Perfetti et al., 2013; Wang et al., 2003), and Chinese as a second language (CSL) learners are more easily influenced by orthography. However, it remains unclear whether the formation of abstract semantic radical identity representations in CSL learners is affected by their degree of deformation and whether there are differences between native and L2 learners. Therefore, this study aims to investigate the impact of the deformation degree of semantic radicals on the abstract semantic radical identity representations of native Chinese speakers and CSL learners.

Numerous studies have demonstrated that radicals are the primary orthographic processing units for both native and non-native Chinese speakers in the development of character recognition and reading (Ho et al., 2003; Shen & Ke, 2007; Wang et al., 2015; Zhang et al., 2016). In the 5,000 most commonly used Chinese characters, 86.72% of semantic radicals provide semantic clues for compound characters(Zhou, 2023). As sub-lexical semantic information, semantic radicals play a crucial role in the character recognition and reading of both native and L2 speakers (Nguyen et al., 2017; Tong & Yip, 2015; Wang et al., 2015; Zhou, 2023). Therefore, understanding learners' mastery of semantic radicals during the learning process is important.

Research on semantic radicals is extensive, but most studies have focused on the radical awareness of Chinese learners, which refers to the learner’s ability to recognize the semantic function of radicals and infer the general meaning of characters. Studies have found that third-grade Chinese children have already mastered the semantic categories of radicals and can use

them to infer the meanings of unfamiliar characters (Shu & Anderson, 1997; Shu & Song, 1993; Wu et al., 2019). For CSL learners whose native language is alphabetic, the structural and semantic features of Chinese characters differ significantly from alphabetic scripts, requiring learners to adopt new learning strategies. Thus, these learners face more difficulties in recognizing and memorizing unfamiliar characters (Chen, 2019). The development of radical knowledge is relatively slow for CSL learners at the beginner to intermediate stages, but their understanding and application of radicals improve significantly from the intermediate to advanced stages (Ma & Hao, 2023; Shen & Ke, 2007). Research on radical awareness focuses on the direct recognition and application of radicals, whereas abstract semantic radical identity representation involves a deeper understanding and generalization of radical semantics. This deeper semantic processing ability may play a more critical role in vocabulary acquisition and reading comprehension for CSL learners. Unfortunately, few studies have addressed the formation of abstract semantic radical identity representations among Chinese learners. Additionally, previous studies on radicals have predominantly used paper-and-pencil tests, which have long response times and involve substantial subjective factors. Although efforts have been made to minimize the effects of random guessing, associations, and confusion with single-component character knowledge (Wong, 2017), it is difficult to completely eliminate these factors. Moreover, paper-and-pencil tests focus on exploring learners' explicit knowledge of radicals without examining the automatic activation of radical semantics during the processes of character recognition and reading.

More importantly, during the simplification process of Chinese characters, semantic radicals have undergone varying degrees of deformation. Although Li et al. (2021) used a same-different judgement task to investigate abstract semantic radical identity representations, they did not

consider the impact of deformation degree. The degree of deformation directly affects orthographic similarity. Jiang and Zhang (2021) found that learners pay special attention to character forms during the second language learning process. Research has also shown that compared to native speakers, L2 learners rely more on orthographic information and focus more on the processing of character forms when learning new characters (Perfetti et al., 2013; Wang et al., 2003). According to the Lexical Quality Hypothesis, a high-quality lexical representation includes accurate and efficient orthography, phonology, and semantics (Perfetti, 2007). For less proficient readers, their lexical systems are relatively immature, meaning their lexical representations may be incomplete or imprecise in terms of orthography, phonology, or semantics. In such cases, they may rely more on the most accessible part of their lexical representation, namely orthographic information, to recognize Chinese characters. Native speakers, on the other hand, possess higher-quality lexical representations and have mastered knowledge of radicals. It is plausible that there is a difference between native speakers and CSL learners in their mastery of semantic radicals with varying degrees of deformation. Therefore, it is necessary to clearly distinguish between different degrees of deformation and examine their effects on native Chinese speakers and CSL learners.

In studies on abstract letter identity representations, researchers often use the masked-priming cross-case letter match task. In this task, a masking stimulus such as "#" is first presented in the center of the screen, with a reference letter displayed above it (the reference letter remains on the screen throughout each trial). Subsequently, the masking stimulus changes to a prime stimulus, and 50 ms later, it changes to a target stimulus. Participants are required to ignore visual differences and quickly and accurately determine whether the initially presented reference letter and the target letter are the same letter. In this task, the similarity of letter case is

used as a variable, and the type of priming is another variable. If the prime stimulus and target stimulus represent the same letter, it is considered "identity prime"; otherwise, it is "control prime." A specific example is shown in Table 1 (a-A-A represents the reference letter-prime letter-target letter). This task presents a problem: in alphabetic languages, identity prime is defined as the prime and target letters having the same letter identity (whether they are the same letter), which can exaggerate the effect of identity prime. Cases like (a-a/A-A) have a form advantage, which can exaggerate the priming effect of (A-a/a-A), such that identity prime being faster than control prime may result from the first two cases having exactly the same form between the prime and target (a to a and A to A), rather than the latter two (a to A or A to a). Therefore, this study aims to improve this task by eliminating the influence of multiple overlaps and identical forms, directly comparing non-form-overlapping identity prime (A-a) with control prime (B-a) to more directly and effectively investigate the issue of abstract representations.

Table 1. Example of case-insensitive matching task.

Similarity	Prime Type	
	Identity prime	Control prime
Dissimilar	a-A-A, A-a-a	A-B-a, a-b-A
	A-A-a, a-a-A	a-B-A, A-b-a
Similar	C-C-c, c-c-C	C-X-c, c-x-C
	C-c-c, c-C-C	C-x-c, c-X-C

The present study

Considering the importance of semantic radicals in learning Chinese characters and the lack of research on abstract semantic radical identity representations, while also overlooking the critical factor of the deformation degree of radicals, this study aims to clearly distinguish the deformation degrees of semantic radicals and to investigate whether deformation degree affects abstract semantic radical identity representations of native speakers and CSL learners. Experiment 1 of this study explores the impact of the degree of semantic radical deformation on

the abstract radical representations through a masked-priming semantic judgment task. Experiment 2 uses a same-different judgement task to further validate the results of Experiment 1. This study hypothesizes that native speakers have already formed abstract semantic radical identity representations and are no longer affected by the degree of deformation. In contrast, the orthographic representations of CSL learners are unstable and more influenced by visual information; therefore, their abstract semantic radical identity representations are expected to be affected by the degree of deformation.

Experiment 1

Experiment 1a: The impact of semantic radical deformation on abstract semantic radical identity representations in native Chinese speakers

Participants

Using G*Power 3.1 software to calculate the required sample size (Faul et al., 2007), when the effect size = 0.25 and $\alpha = 0.05$, a total of 24 participants are needed to achieve a statistical power of 0.80. A total of 50 university students with Mandarin as their native language from Tianjin Normal University were actually recruited(41 females), aged 18 to 25 ($M = 20.56$, $SD = 1.72$). All participants had normal uncorrected or corrected vision and no history of reading disabilities.

Experimental Design

A 2 (Deformation Degree: high, low) × 2 (Prime Type: identity prime, control prime) within-subjects design was used. Identity prime refers to the prime and target sharing the same semantics, while in control prime, the prime and target have no relation. The dependent variables were reaction time and accuracy.

Materials

Twenty-one native Chinese speakers (who did not participate in the study) were pre-selected to rate the visual similarity of pairs of Chinese character radicals on a 5-point Likert scale (1 = very dissimilar; 5 = very similar). Based on the ratings, 12 pairs of radicals with a high degree of deformation (e.g., “水−氵”; “衣−衤”) (M = 2.63, SD = 1.3) and 12 pairs with a low degree of deformation (“木−   ”; “牛−   ”) (M = 4.66, SD = 0.56) were selected. The two groups had significant visual differences, t (40) = -23.34, p < 0.001. An additional 21 native speakers evaluated the semantic relationship between the prime and target. There was a significant difference in semantic association between identity prime (M = 4.21, SD = 1.08) and control prime (M = 1.33, SD = 0.64) with the target stimuli, t (40) = 56.30, p < 0.001, indicating no semantic relationship between the prime and target in the control condition. To avoid the influence of radical familiarity, familiarity ratings from Lü et al. (2015) were used to assess radicals with a high degree of deformation (M = 3.45, SD = 0.20) and those with a low degree (M = 3.41, SD = 0.19). The results showed no significant difference in familiarity between the two deformation degrees, t (22) = 0.49, p = 0.63.

Instruments and Procedure

The experiment was programmed using E-Prime 2.0 software and presented on a Lenovo 14-inch laptop, which also recorded the results. The procedure began with a fixation point "+" displayed for 500 ms, followed by a reference character at the top of the screen for 1000 ms and a mask in the center of the screen. The prime stimulus then replaced the mask, and 50 ms later, the target stimulus appeared (Kinoshita & Kaplan, 2008; Schubert et al., 2018). To minimize the influence of physical similarity, the prime stimulus was presented in KaiTi font and the target stimulus in SongTi font. Participants were required to press a key to judge whether the initially presented

reference character had the same meaning as the target stimulus. If they were the same, they pressed the "F" key; otherwise, they pressed the "J" key. The experiment consisted of 216 trials. Before the formal experiment, participants completed 12 practice trials to ensure they understood the task requirements. They could proceed to the formal experiment only if they achieved 90% accuracy in the practice trials; otherwise, they repeated the practice. The entire experiment took approximately 15 minutes. The experimental procedure is illustrated in Figure 1.

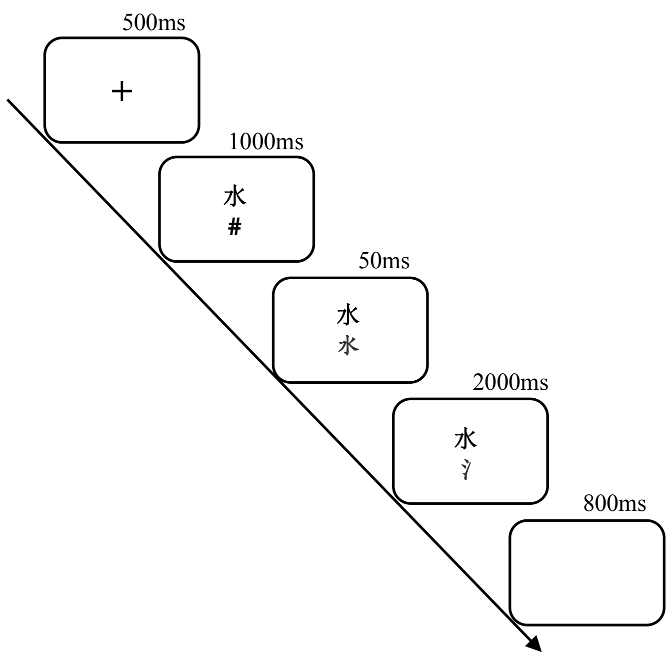

Figure 1. Illustration of experimental procedure in Experiment 1.

Results and Analysis

The R software (version 4.3.1) was used to run the lme4 package. A linear mixed model (LMM) was used to analyze reaction times, and a generalized linear mixed model (GLMM) was used to analyze accuracy. Participants and items were treated as crossed random factors (Baayen et al., 2008), deformation degree and prime type were included as fixed factors in the model, considering random intercepts and slopes for both participants and items (Barr et al., 2013). All

analyses started with the maximum random effects model. If the maximum model could not fit successfully, the model was simplified until a successful fit was achieved.

Data points that were more than ±3 standard deviations from the mean for each participant at each level were excluded (1.6% of the total data). Only trials with correct "same" responses were included in the analysis (Schubert et al., 2018). The average reaction times and accuracy for different prime types at different deformation degrees are shown in Tables 2 and 3.

Table 2. Average reaction times (SD) for each condition in Experiment 1a.

Prime Type	Deformation Degree	
	High	Low
Identity Prime	740.59（259.18）	603.49（185.40）
Control Prime	760.21（265.50）	658.48（177.78）

Note. Reaction time is measured in milliseconds, with standard deviation in parentheses. The same applies to the following sections.

Analysis of the reaction time data showed a significant main effect of deformation degree $b = -0.16$, $SE = 0.01$, $t = -13.83$, $p < 0.001$, indicating that reaction times for radicals with a high degree of deformation were slower than those with a low degree of deformation. The main effect of prime type was significant $b = -0.06$, $SE = 0.01$, $t = -5.80$, $p < 0.001$, showing that reactions under identity prime were faster than those under control prime. The interaction between the two factors was significant $b = -0.07$, $SE = 0.02$, $t = -3.10$, $p < 0.01$. Simple effects analysis (see Figure 2) indicated that for radicals with a low degree of deformation, identity prime was significantly faster than control prime $b = 0.09$, $SE = 0.01$, $t = 6.53$, $p < 0.001$. For radicals with a high degree of deformation, identity prime was still faster than control prime, but only marginally significant $b = 0.03$, $SE = 0.02$, $t = 1.84$, $p = 0.066$. These results suggest that native speakers can form abstract semantic radical identity representations regardless of the degree of deformation. However, radicals with a higher degree of deformation may present more challenges in this process compared to those with a lower degree of deformation.

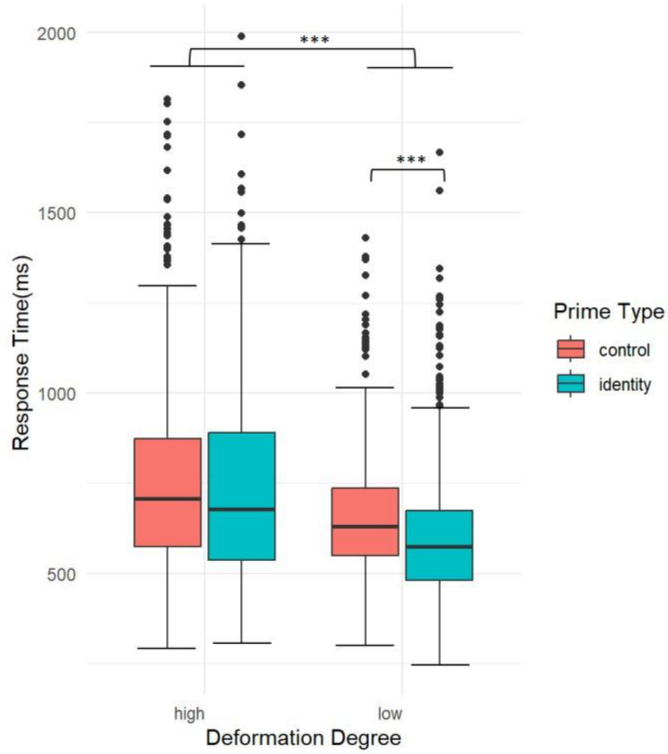

Figure 2. Reaction time results for each condition in Experiment 1a. ***p < 0.001, **p < 0.01, same below.

The accuracy results showed a significant main effect of deformation degree $b = 6.12$, $SE = 2.22$, $z = 2.76$, $p < 0.01$, indicating that accuracy for radicals with a high degree of deformation was lower than for those with a low degree of deformation. This may be because the latter have an advantage in character form, illustrating that the close connection between form and meaning in Chinese characters (Perfetti & Tan, 1998), and suggesting that orthography plays an important role in Chinese character recognition, and that the current priming duration is sensitive to the activation of orthographic information.

Table 3. Accuracy for each condition in Experiment 1a.

Prime Type	Deformation Degree	
	High	Low
Identity Prime	0.85（0.36）	0.99（0.08）
Control Prime	0.86（0.35）	0.99（0.11）

Experiment 1b: The impact of semantic radical deformation on abstract semantic radical identity representations in CSL Learners

Participants

The sample size estimate was the same as in Experiment 1a. Forty-five CSL learners from Tianjin Normal University were recruited (33 females), aged 18 to 33 years (M = 22.89, SD = 2.64). All participants had normal or corrected-to-normal vision and no history of reading disorders.

The third edition of the Language History Questionnaire (LHQ3) developed by Li et al. (2019) was used to measure participants' native language backgrounds and HSK levels. The native languages of the participants were as follows: Vietnamese (16 participants, 35.6%), Thai (22 participants, 48.9%), and others (7 participants, 15.6%) including Arabic, Indonesian, Khmer (1 participant each), and Malay (4 participants). Twenty-seven students (60%) passed the HSK 5, and 18 students (40%) passed the HSK 6. According to the Chinese Proficiency Grading Standards for International Chinese Language Education, HSK 4–6 correspond to intermediate Chinese proficiency.

Experimental Design, Materials, and Procedure

The design, materials, and procedure were the same as in Experiment 1a. The selected semantic radicals and their corresponding single-component characters were within HSK 4–5.

Results and Analysis

Data deletion and screening criteria were the same as in Experiment 1a, resulting in the deletion of 1.5% of the total data. The average reaction times and accuracy for different prime types at different deformation degrees are shown in Tables 4 and 5.

Analysis of reaction times showed a significant main effect of deformation degree $b = -0.15$, $SE = 0.03$, $t = -7.97$, $p < 0.001$, indicating that reaction times for radicals with a high degree of deformation were slower than those with a low degree of deformation. The main effect of prime type was also significant $b = -0.05$, $SE = 0.02$, $t = -3.01$, $p < 0.01$, showing that reactions under identity prime were faster than under control prime. The interaction between the two factors was significant $b = -0.10$, $SE = 0.03$, $t = -3.45$, $p < 0.001$. Simple effects analysis (see Figure 3) indicated that for radicals with a low degree of deformation, identity prime was significantly faster than control prime $b = 0.09$, $SE = 0.02$, $t = 4.82$, $p < 0.001$. For radicals with a high degree of deformation, there was no significant difference between identity and control prime $b = -0.003$, $SE = 0.02$, $t = -0.14$, $p = 0.89$. These results suggest that forming abstract representations of radicals with a high degree of deformation is challenging for CSL learners, while radicals with a low degree of deformation have an orthographic advantage and are more easily mastered by CSL learners.

Table 4. Average reaction times (SD) for each condition in Experiment 1b.

Prime Type	Deformation Degree	
	High	Low
Identity Prime	827.28（304.75）	681.14（250.07）
Control Prime	831.55（303.38）	746.18（262.04）

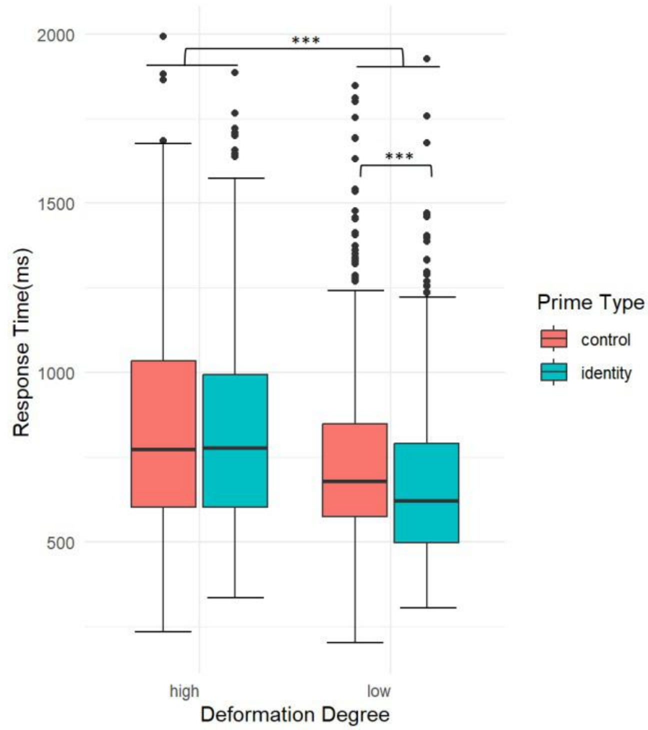

Figure 3. Reaction time results for each condition in Experiment 1b.

The accuracy results indicated a significant main effect of deformation degree $b = 2.18$, $SE = 0.29$, $z = 7.57$, $p < 0.001$, showing that the accuracy for radicals with a high degree of deformation was lower than for those with a low degree of deformation. Consistent with the results for native speakers, radicals with a low degree of deformation are easier to master. The main effect of prime type was also significant $b = 0.35$, $SE = 0.16$, $z = 2.21$, $p < 0.05$, indicating that identity prime has a higher accuracy than control prime.

Table 5. Accuracy for each condition in Experiment 1b.

Prime Type	Deformation Degree	
	High	Low
Identity Prime	0.76（0.43）	0.95（0.22）
Control Prime	0.73（0.44）	0.92（0.27）

Analyzing each group separately allows for a clear observation of specific trends within the two groups and enables a more detailed exploration of their performances under different

deformation degrees and prime types. However, a combined analysis considers data from both native and CSL learners simultaneously, providing a comprehensive comparison of their differences and similarities. A combined analysis of the reaction time data for native and CSL learners revealed significant effects for several factors: deformation degree $b = -0.16$, $SE = 0.01$, $t = -14.49$, $p < 0.001$, prime type $b = -0.05$, $SE = 0.01$, $t = -6.12$, $p < 0.001$, and participant group $b = -0.10$, $SE = 0.03$, $t = -3.05$, $p < 0.01$, indicating that native speakers responded significantly faster than CSL learners. There was a significant interaction between deformation degree and prime type $b = -0.08$, $SE = 0.02$, $t = -4.70$, $p < 0.001$. Simple effects analysis showed that for radicals with a low degree of deformation, identity prime was significantly faster than control prime $b = 0.09$, $SE = 0.02$, $t = 8.05$, $p < 0.001$. However, for radicals with a high degree of deformation, there was no significant difference between identity and control prime $b = 0.01$, $SE = 0.01$, $t = 0.96$, $p = 0.34$. No three-way interaction was found, indicating that both native and CSL learners showed faster identity prime than control prime for radicals with a low degree of deformation, while there was no significant difference for radicals with a high degree of deformation. The results are presented in Table 6.

Table 6. Average reaction times from the combined analysis in Experiment 1.

Prime Type	Native		CSL	
	HDD	LDD	HDD	LDD
Identity Prime	740.59（259.18）	603.49（185.40）	827.28（304.75）	681.14（250.07）
Control Prime	760.21（265.50）	658.48（177.78）	831.55（303.38）	746.18（262.04）

Note. HDD indicates high degree of deformation; LDD indicates low degree of deformation.

In summary, the results from the separate analyses in Experiment 1 showed that both native and CSL learners can form abstract identity representations of radicals with a low degree of deformation. The primary difference between the two groups is in the radicals with a high degree

of deformation, where CSL learners failed to form abstract identity representations. This indicates that orthography plays an important role in learning Chinese characters. For radicals with a high degree of deformation, native speakers responded faster under identity prime than control prime, but this was only marginally significant. The combined analysis of data from native and CSL learners showed no significant differences between the two groups. This may be because the difference in reaction times between the two prime types for high-deformation radicals was small for native speakers. As a result, this difference was offset by the trend in CSL learners, leading to no overall difference in the combined analysis. However, Li et al. (2021) used a same-different judgment task to investigate abstract semantic radical identity representations in native speakers (mostly using radicals with a high degree of deformation) and found that native speakers had already formed stable abstract representations. The weaker effect found in native speakers in this study may be related to the priming task used. The priming duration in this study was 50 ms, and there is ongoing debate about the time required for semantic activation (Chen & Shu, 2001; Perfetti & Tan, 1998). Some research has found that only orthographic activation occurs at this priming duration (Tan et al., 1995), and the activation strength of semantic information may be relatively weak, making reaction time measures less sensitive to reflect activation levels. Given that the task might influence participants' responses and that the main difference between native and CSL speakers is concentrated on radicals with a high degree of deformation, this study aims to further investigate the differences in abstract representations of highly deformed radicals between native and CSL learners using a same-different judgment task.

Experiment 2

Experiment 2a: The impact of semantic radical deformation on abstract semantic radical identity representations in native Chinese speakers: evidence from a same-different judgment task

Participants

The sample size estimate was the same as in Experiment 1. A total of 28 participants were required, and 40 university students with Mandarin as their native language from Tianjin Normal University were actually recruited (39 females), aged 17 to 24 years (M = 19.55, SD = 1.45). All participants had normal or corrected-to-normal vision and no history of reading disorders.

Experimental Design

A single-factor, three-level within-subjects design was used (experimental conditions: consistent condition, identity condition, control condition). The dependent variables were reaction time and accuracy.

Materials

Twelve pairs of radicals with a high degree of deformation from Experiment 1 were used. Twenty additional native Chinese speakers rated the visual and semantic similarity of the three experimental conditions on a 5-point Likert scale (1 = very dissimilar; 5 = very similar). For visual similarity, the consistent condition (M = 4.81, SD = 0.44) scored higher than the identity (M = 1.68, SD = 0.65) and control conditions (M = 1.40, SD = 0.61), F (2, 57) = 230.56, $p <$ 0.001. There was no difference between the identity and control conditions, t (38) = 1.43, p = 0.16, indicating that both identity and control conditions were visually dissimilar. For semantic similarity, the consistent (M = 4.93, SD = 0.19) and identity conditions (M = 3.64, SD = 0.70)

scored higher than the control condition (*M* = 1.45, *SD* = 0.52), F (2, 57) = 243.63, $p < 0.001$, indicating that the control condition had no semantic relationship. Examples of the materials are shown in Table 7.

Table 7. Examples of materials used in Experiment 2.

Experimental Condition	Example
Consistent	水-水
Identity	水-氵
Control	水-马

Instruments and Procedure

The instruments were the same as in Experiment 1. A fixation point "+" was presented for 500 ms, followed by a pair of stimuli for 2500 ms. To prevent the stimuli pair from being perceived as a compound character, the two stimuli were presented diagonally, with each stimulus randomly positioned. Participants were required to press a key to judge whether the presented stimulus pair was visually similar. If similar, they pressed the "F" key; otherwise, they pressed the "J" key. The experiment consisted of 192 trials. To ensure that participants understood the task requirements, they completed 10 practice trials before the formal experiment and were only allowed to proceed if they achieved 90% accuracy. The experiment took approximately 10 minutes. The experimental procedure is illustrated in Figure 4.

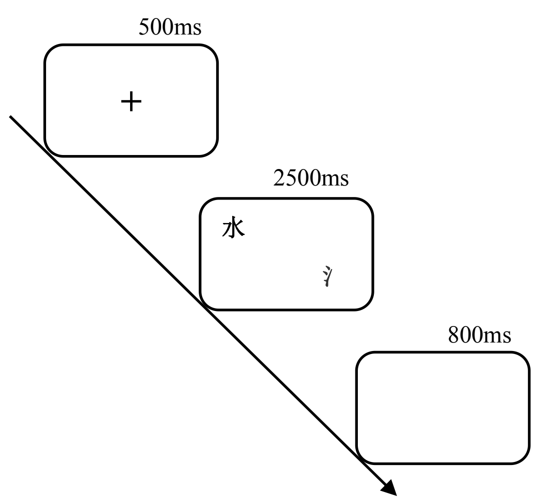

Figure 4. Illustration of experimental procedure in Experiment 2.

Results and Analysis

The data deletion criteria were the same as in Experiment 1, resulting in the deletion of 1.6% of the total data. Only correct "different" responses were included in the analysis (Li et al., 2021). The average reaction times and accuracy under different experimental conditions are shown in Table 8.

For reaction times, the identity condition yielded significantly longer reaction times than the control condition $b = 0.07$, $SE = 0.01$, $t = 4.88$, $p < 0.001$, see Figure 5. The identity condition also yielded significantly lower accuracy than that of the control condition $b = -2.35$, $SE = 0.62$, $z = -3.77$, $p < 0.001$. These results indicate that when responding "different" to the visually distinct identity condition, it is difficult to suppress the information that the two radicals have the same meaning. Thus, reaction times were longer and accuracy were lower in the identity condition compared to the control condition. This suggests that native speakers have already formed abstract identity representations for radicals with a high degree of deformation.

Table 8. Average reaction times (SD) and accuracy (SD) for each condition in Experiment 2a.

Index	Consistent Condition	Identity Condition	Control Condition
Reaction Time	638.15（182.48）	792.01（270.17）	757.61（208.22）
Accuracy	0.98（0.12）	0.78（0.41）	0.97（0.16）

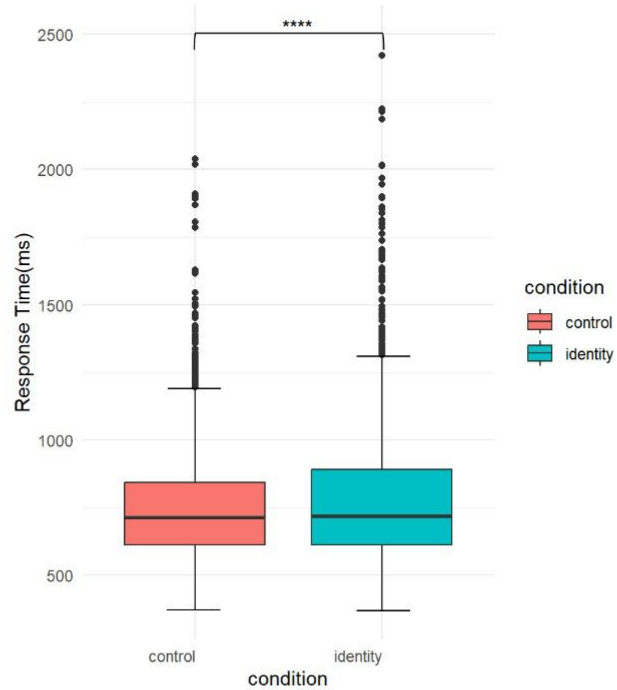

Figure 5. Reaction time results for Experiment 2a.

Experiment 2b: The impact of semantic radical deformation on abstract semantic radical identity representations in CSL learners: Evidence from a same-different judgment task

Participants

The sample size estimate was the same as before. Forty-three CSL learners from Tianjin Normal University were recruited (30 females), aged 18 to 29 years (M = 22.65, SD = 3.01). All participants had normal or corrected-to-normal vision and no history of reading disorders.

The third edition of the Language History Questionnaire (LHQ3) developed by Li et al. (2019) was used to measure participants' native language backgrounds and HSK levels. The native languages of the participants were as follows: Vietnamese (17 participants, 39.5%), Thai (15 participants, 34.9%), and others (11 participants, 25.6%) including Arabic, Tajik, French, Kyrgyz, and Indonesian (1 participant each), English (2 participants), and Khmer (4 participants). Twenty-three students (53.5%) passed the HSK5, and Twenty students (46.5%) passed the HSK6,

indicating all participants had intermediate Chinese proficiency. Additionally, each participant completed the LexCHI test (Wen et al., 2024), which provides an objective assessment of learners' Chinese proficiency.

Experimental Design, Materials, and Procedure

The design, materials, and procedure were the same as in Experiment 2a.

Results and Analysis

The data deletion criteria were the same as before, resulting in the deletion of 1.4% of the total data. The average reaction times and accuracy under different experimental conditions are shown in Table 9.

For reaction times, the identity condition yielded significantly longer reaction times than the control condition $b = 0.08$, $SE = 0.02$, $t = 4.61$, $p < 0.001$, see Figure 6. For accuracy, the identity condition was significantly lower than the control condition $b = -2.29$, $SE = 0.46$, $z = -4.96$, $p < 0.001$. These results indicate that for CSL learners, when the stimulus pair is visually unrelated but shares semantic information, the influence on judgment is also inhibitory. This suggests that L2 learners have formed abstract identity representations for radicals with a high degree of deformation.

Table 9. Average reaction times (SD) and accuracy (SD) for each condition in Experiment 2b.

Index	Consistent Condition	Identity Condition	Control Condition
Reaction Time	701.38（203.06）	858.78（302.54）	831.90（241.10）
Accuracy	0.98（0.12）	0.72（0.45）	0.98（0.14）

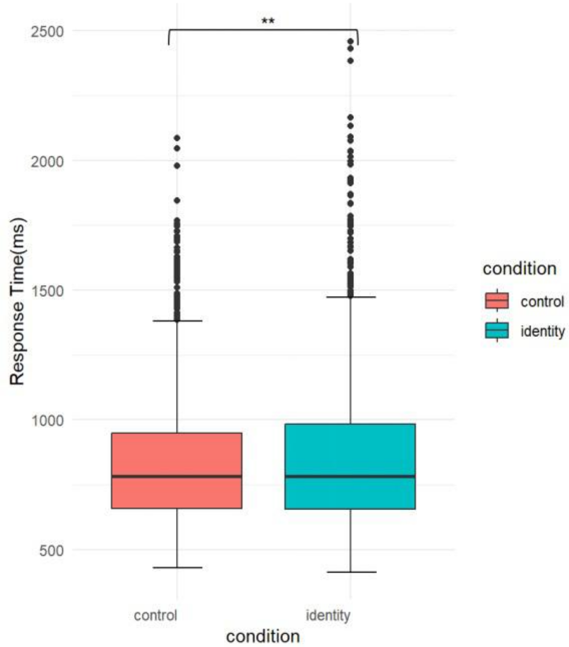

Figure 6. Reaction time results for Experiment 2b.

A combined analysis of the reaction time data for native and CSL learners revealed significant main effects. The main effect of experimental condition was significant b = 0.07, SE = 0.01, t = 8.65, $p < 0.001$, with reaction times being significantly longer under the identity condition than the control condition. The main effect of participant group was also significant b = -0.10, SE = 0.04, t = -2.25, $p < 0.05$, indicating that reaction times for L2 learners were significantly longer than those for native speakers. There was no interaction between the two factors, indicating that both native and CSL Learners showed inhibitory effects under the identity condition. The results are presented in Table 10.

Table 10. Average reaction times (SD) from the combined analysis in Experiment 2.

Experimental Condition	Participant Group	
	Native	CSL
Identity	792.01（270.17）	858.78（302.54）
Control	757.61（208.22）	831.90（241.10）

To clarify the relationship between Chinese proficiency and abstract semantic radical identity representation in CSL learners, a correlation analysis was conducted between LexCHI test scores and reaction times under the identity condition. The results showed a significant positive correlation $r = 0.31$, $p < 0.05$, indicating that higher LexCHI scores are associated with longer reaction times. This suggests that as CSL learners' Chinese proficiency improves, their abstract representations of semantic radicals become more stable. Consequently, an inhibitory effect is observed when making "no" judgments on visually different but semantically related radicals.

In summary, the results of Experiment 2 indicate that both native and CSL learners can form abstract identity representations for radicals with a high degree of deformation. The results for L2 learners differ from Experiment 1, which may be due to differences in tasks. For CSL learners, making consistent responses to radicals with completely different forms under the very short priming duration in Experiment 1 may have been more challenging. The priming task in Experiment 1 may have primarily focused on implicit activation processes, where stimuli are more difficult to be consciously perceived and processed. In contrast, the stimuli in the same-different judgment task are more direct and apparent, potentially influencing participants' responses and the experimental results. Experiment 2 further revealed that as L2 learners' Chinese proficiency increases, their abstract identity representations of semantic radicals become more stable.

General Discussion

This study explored the impact of semantic radical deformation degree on abstract semantic radical identity representation in Chinese learners using different tasks. The results show that although both native and CSL learners can form abstract representations for radicals with

varying degrees of deformation, the experimental tasks influence the results. In Experiment 1, native and CSL participants performed differently for highly deformed radicals, with the latter group struggling to form representations. In contrast, Experiment 2 showed consistent performance between native and CSL participants, indicating that both groups formed abstract representations for highly deformed radicals.

The impact of semantic radical deformation on abstract semantic radical identity representations in native and CSL speakers

The study found that both native Chinese speakers and CSL learners have formed abstract semantic radical identity representations, but the impact of deformation degree is greater for CSL learners than for native speakers. This is evident from CSL learners' varying performance on highly deformed radicals across tasks: no abstract representation was observed in the masked priming semantic judgment task, but it was observed in the same-different judgment task, suggesting that L2 learners' abstract representations are unstable. For native speakers, reaction times were faster for identity prime than for control prime in the semantic judgment task with highly deformed radicals, but the difference was only marginally significant. This difference disappeared in the combined analysis of native and L2 speakers. Aside from task influences, this could be because Chinese, as a logographic language, has a close form-meaning connection and complex character structures (Perfetti & Tan, 1998). This tendency leads native speakers to rely on orthographic information, and in the recognition of Chinese characters, readers access meaning through the processing of orthographic and phonological information (Xu et al., 1999). While highly deformed radicals possess both form and meaning, they lack phonological information compared lowly deformed radicals (Tong et al., 2017). This may cause readers to rely more on orthography when accessing the meaning of highly deformed radicals, leading to a

weak tendency for native speakers to form abstract representations for these radicals in the semantic judgment task. CSL learners typically need to focus more on the orthography of Chinese characters (Loh et al., 2018), making it more challenging for them to form representations of highly deformed radicals.

Zou et al. (2019) used event-related potentials (ERP) to record performance in a masked-priming lexical decision task, comparing the processing of character semantic radicals and non-character semantic radicals. The results showed that these two types of semantic radicals are processed differently; character semantic radicals led to stronger semantic activation, resulting in a more robust priming effect on the N400, a semantic processing indicator, compared to non-character semantic radicals. The meanings of non-character semantic radicals are typically acquired through classroom instruction, dictionaries, or abstracted from the characters they are part of. Therefore, their connection to meaning is weaker, requiring more time to analyze the visual form of the radical before retrieving its meaning. highly deformed radicals are mostly non-character semantic radicals, while lowly deformed radicals are mostly character semantic radicals. This study also found that learners form representations more easily for low-deformation radicals, while high-deformation radicals present more visual interference. This provides new evidence supporting the difference in processing methods between the two types of radicals.

Further analysis of the relationship between Chinese proficiency and abstract semantic radical identity representation in CSL learners revealed that abstract representations become more stable as proficiency increases. This suggests that as learners' Chinese proficiency improves, they can use semantic radical information more effectively. This finding is consistent with previous paper-and-pencil test results, indicating that intermediate to advanced L2 learners

have already mastered and applied knowledge of semantic radicals (Ma & Hao, 2023; Shen & Ke, 2007). The present study clearly distinguished between different degrees of radical deformation, leading to more precise conclusions and revealing the automatic activation of radical semantics.

The influence of experimental tasks on abstract semantic radical identity representations in native speakers and CSL learners

This study found that experimental tasks affect the results. Experiment 1 showed that both native speakers and CSL learners could form abstract representations for radicals with a low degree of deformation. However, for highly deformed radicals, L2 learners have not yet formed representations, while native speakers showed a relatively clear trend of establishing abstract representations. Considering that Li et al. (2021) demonstrated through other tasks that native speakers have already formed abstract semantic radical identity representations, this study suggests that while the task used in Experiment 1 can clearly investigate radicals with different degrees of deformation, and the masked priming task minimizes strategic effects, the semantic priming effect is unstable during subliminal priming (De Wit & Kinoshita, 2015; Draine & Greenwald, 1998). Radicals with a low degree of deformation have an orthographic advantage, while those with a high degree have significant orthographic differences, placing higher demands on information processing ability in Chinese learners. As a result, L2 learners found it difficult to form representations. This led to Experiment 1 only finding that both native and L2 speakers formed abstract representations for radicals with a low degree of deformation, while L2 learners exhibited a floor effect for highly deformed radicals. Previous studies using masked priming tasks have also found that native speakers exhibit priming effects with very short prime durations combined with masking (Forster & Davis, 1984; Sereno, 1991). However, non-native speakers,

especially when the two languages involved are different writing systems, show limited L2 processing efficiency, so no cross-language priming is observed (Grainger & Beauvillain, 1988; Gollan et al., 1997). Additionally, studies using the same task to investigate abstract letter identity representations in alphabetic languages have found a greater effect (Carreiras et al., 2012; Schubert et al., 2018). This could be because, compared to upper and lowercase letters in alphabetic languages, highly deformed radicals are more orthographically dissimilar, and this study further improved the task by directly comparing the differences between non-form-overlapping identity prime and control prime, eliminating conditions where the prime and target stimuli were completely orthographically identical. This exclusion of priming effects induced by orthographic consistency could explain why the priming effect found in this study was smaller than those in studies related to alphabetic languages.

Experiment 2, using a same-different judgment task, found that both native speakers and CSL learners can form abstract representations for radicals with a high degree of deformation. This task involved directly judging whether the orthography was the same, examining the potential influence of semantic relationships. Compared to Experiment 1, this task allowed participants to directly observe and compare stimuli, which likely reduced cognitive load and made it easier for participants to activate and use semantic information from the radicals. Therefore, Experiment 2 clearly demonstrated that both native and L2 speakers form abstract representations for highly deformed radicals.

Overall, this study builds on existing research on abstract letter identity representations in alphabetic languages and further reveals the existence of abstract semantic radical identity representations in the Chinese writing system, highlighting a universal cognitive mechanism for cross-linguistic abstract representation. The study found that Chinese learners can overlook the

visual form of radicals and represent radicals with different forms as having the same semantic identity or concept, indicating that they have developed the ability to form abstract representations of radicals. This ability goes beyond simple recognition of visual forms and involves understanding and generalizing the deeper semantics of radicals, which is crucial for learning and mastering Chinese characters.

This study also has important implications for teaching Chinese as a second language. First, because CSL learners are easily influenced by orthography and have unstable mastery of highly deformed radicals, it is essential to focus on teaching the meanings of these radicals. For example, teaching can classify and explain that the radical "氵" is related to water, while the speech radical "讠" is related to speaking. Second, teachers should guide learners to recognize that the position and form of components in different characters can vary, and they should summarize and consolidate this understanding as learners increase their character recognition. Finally, it is important to emphasize frequently used single-component characters, especially those that can serve as semantic radicals, and to highlight the connection between the two forms. After learning a certain number of phonograms, learners should classify the radicals they have learned to lay a foundation for learning more phonograms in the future.

Future Directions

This study only included intermediate-level CSL learners. Future research could expand to include lower-level L2 learners to further explore the differences in radical cognition among L2 learners of different proficiency levels. This can help to adjust and optimize teaching strategies to better meet the needs of learners at different levels. Additionally, while the relationship between radical awareness and Chinese character recognition and reading comprehension has been extensively studied (Ho et al., 2003; Shen & Ke, 2007; Tong et al., 2017), future research

should focus on a more in-depth exploration of the semantic effects of radicals. This involves developing and validating instructional strategies that can facilitate learners' formation of semantic representations of radicals at an early stage, thereby improving their ability for vocabulary development.

Conclusion

This study employed two experimental tasks to investigate the impact of semantic radical deformation on abstract semantic radical identity representations in Chinese learners. The results indicate that both native Chinese speakers and L2 learners have mastered radicals with different degrees of deformation, but L2 learners' mastery is less stable and more influenced by the experimental tasks. Understanding the formation of abstract semantic radical identity representations in Chinese learners helps deepen our understanding of the learning process for radicals, and it also has potential practical application value for teaching Chinese as a second language.

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